

Improved Traceability of Mission Concept to Requirements Using Model Based Systems Engineering

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AEROSPACE
ENGINEERING

CAL POLY • SAN LUIS OBISPO

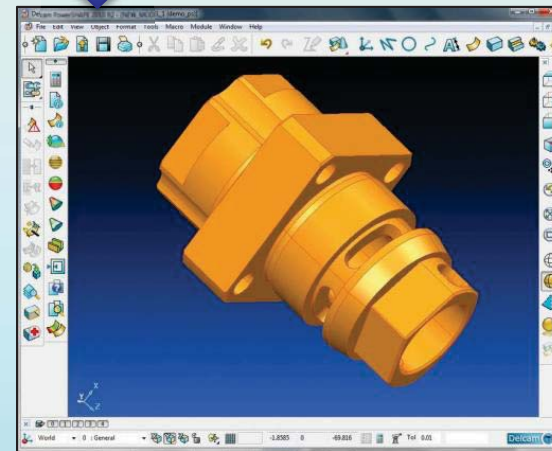
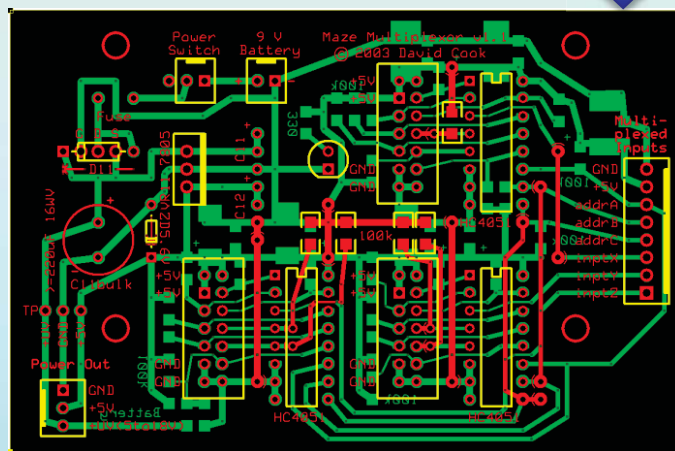
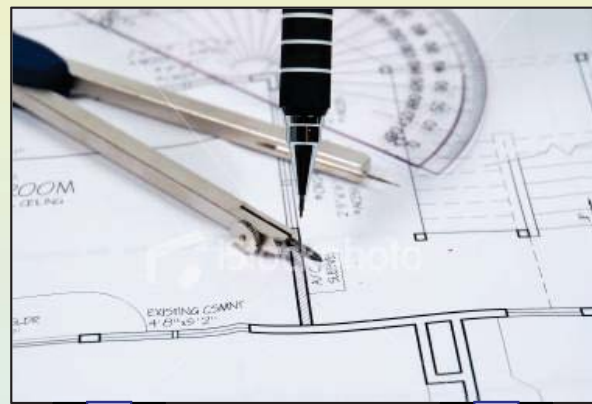
Outline

- Background
- Thesis Objective
- Methodology
- Results
- Implications of Research



Background

Model-Based Approach



Wikipedia and Google Image Search



Background

“Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”

- *Systems Engineering Vision 2020*, INCOSE-TP-2004-004-02, September 2007



Background

Document-Based SE (DBSE) vs. MBSE

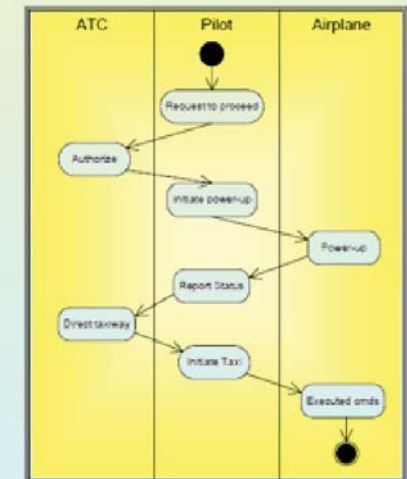
Past



SE Artifacts

- Specifications
- Interface requirements
- System design
- Analysis & Trade-off
- Test plans

Future



Document centric

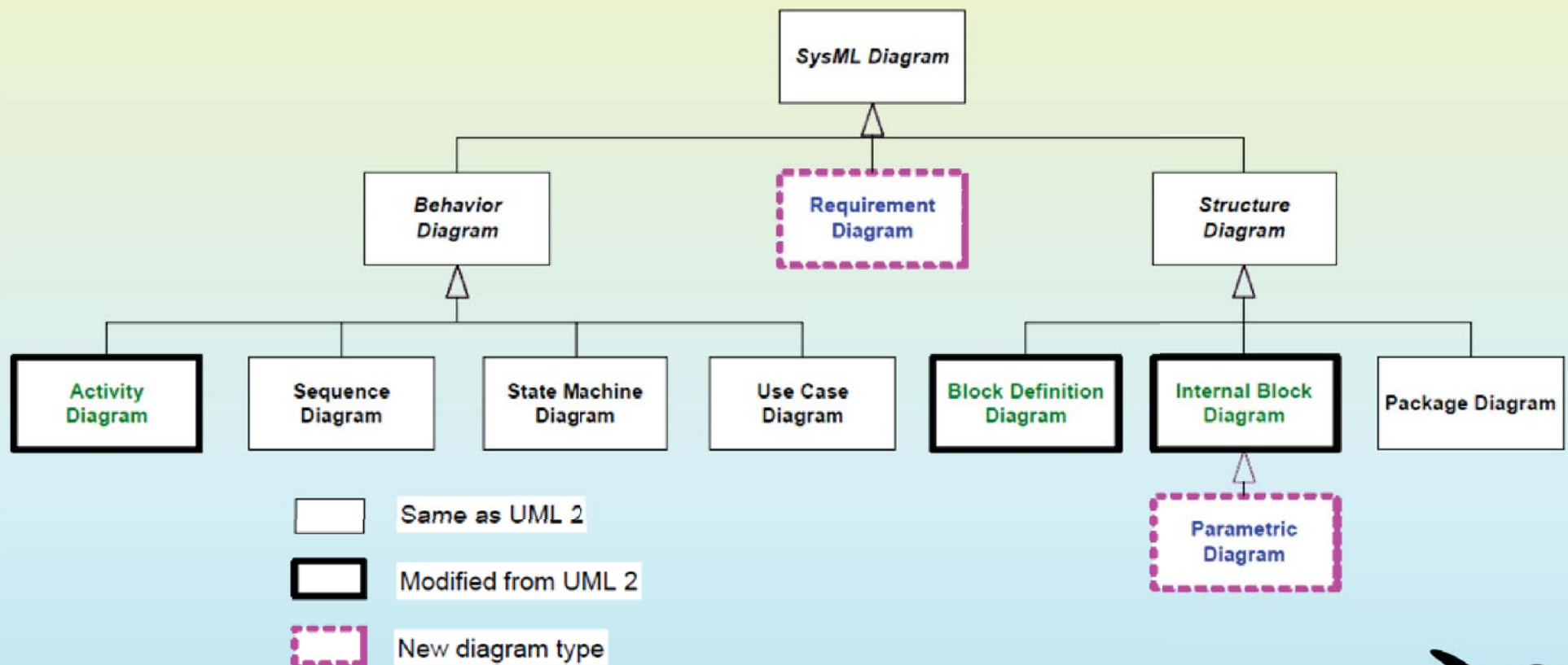
Model centric

INCOSE Model Based Systems Engineering (MBSE) Initiative, June 2007



Background

Systems Modeling Language (SysML)



SysML Tutorial, September 2009. Copyright © 2006-2008 by Object Management Group



Background

- Perceived Benefits of MBSE
 - Communications
 - Development risk
 - Quality
 - Productivity
 - Leveraging model across life-cycle
 - Knowledge transfer

A Practical Guide to SysML, 2nd Edition, 2012



Background

- Research
 - Documentation of early modeling efforts
 - Descriptions of potential benefits from modeling
 - Lack of work presenting direct evidence of MBSE benefits



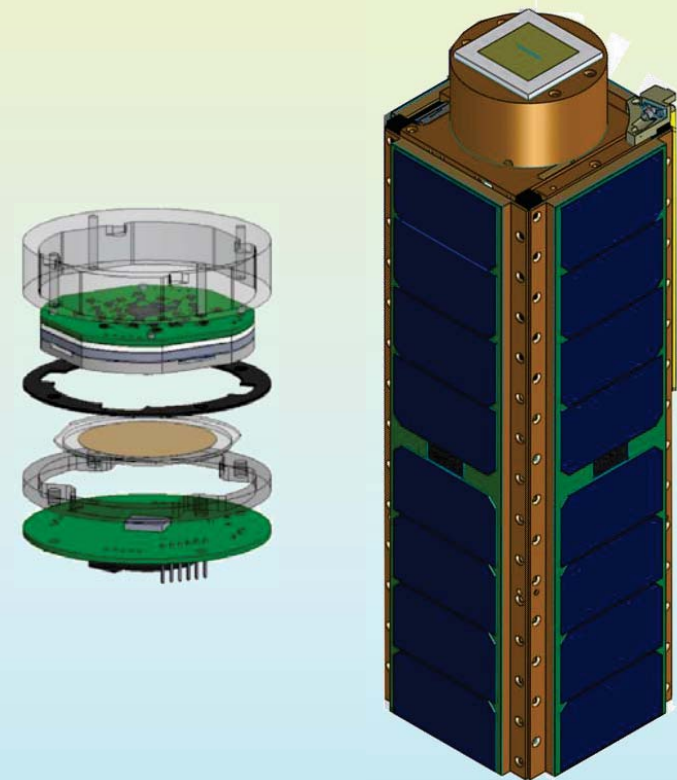
Thesis Objective

Demonstrate MBSE utility in tracing mission concept to requirements



Methodology

- Model NASA Ames SporeSat
 - 3U CubeSat
 - Studies fern spore growth in varying gravity environments

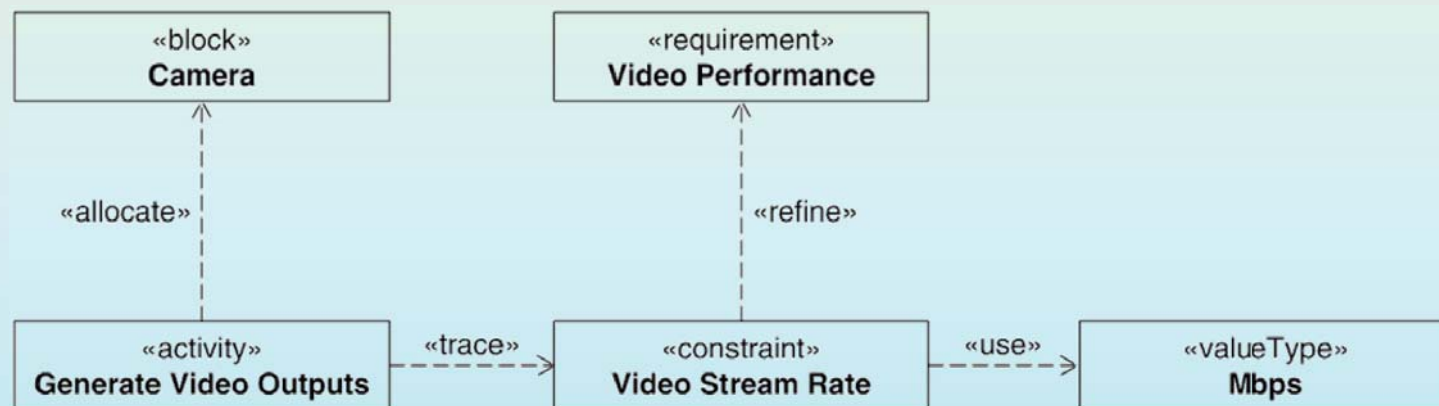


SporeSat NASA Fact Sheet, FS #2013-04-04-ARC, 2013



Methodology

- Create Mission Model
 - Mission Architecture and CONOPS
 - Mission Requirements
 - Dependency relationships



A Practical Guide to SysML, 2nd Edition, 2012



Methodology

- Analyze
 - Completeness and ambiguity of requirements
 - Consistency between requirements and design

satisfy dependency Matrix		S2 Availability	S1 Operating Environment	S1.2 24/7 Operation	S1.1 All Weather Operation	D1 Sensor Decision
Structure						
Camera						
Camera Module						
Camera Module						
Camera Housing						
Camera						
Electronics Assembly						
Mount Assembly						

deriveReq dependency Matrix		S2 Availability	S1 Operating Environment	S1.2 24/7 Operation	S1.1 All Weather Operation	D1 Sensor Decision
Customer Specification						
S2 Availability						
S1 Operating Environm?						
S1 Operating Environm?						
S1.2 24/7 Operation						
S1.1 All Weather Op?						
System Specification						
D1 Sensor Decision						

A Practical Guide to SysML, 2nd Edition, 2012



Methodology

3 SPORESAT SCIENCE REQUIREMENTS

3.1 General Requirements

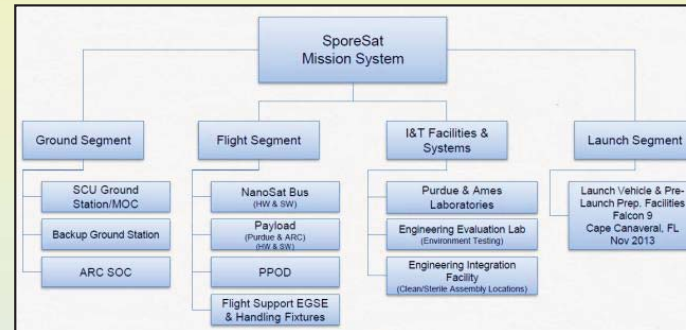
The SporeSat systems shall comply with to ensure experiment viability.

3.1.1 Experiment Configuration

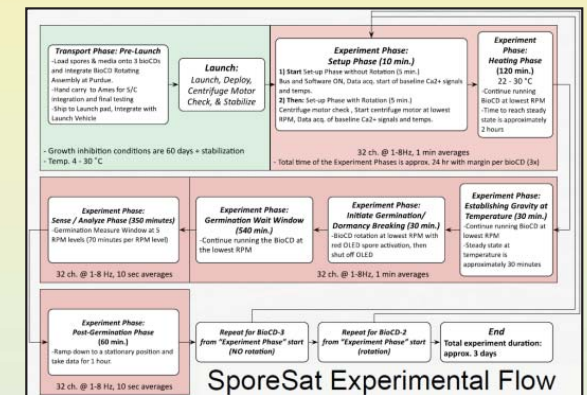
3.1.1.1 Artificial Gravity (Acceleration) P

Means shall be provided to artific supports the immobilization, germ multiple spores of Ceratopteris ric

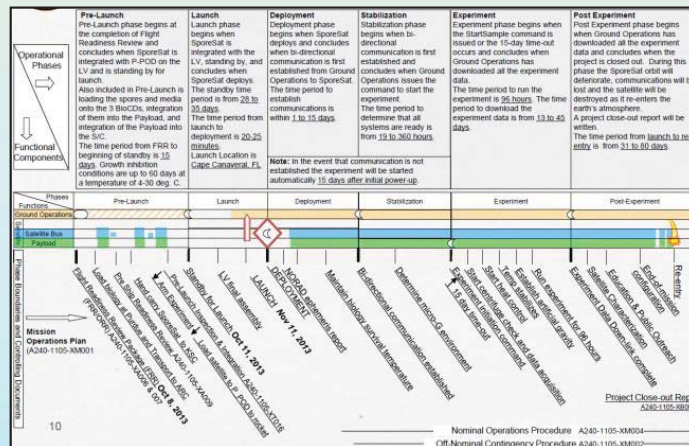
Requirements (Document)



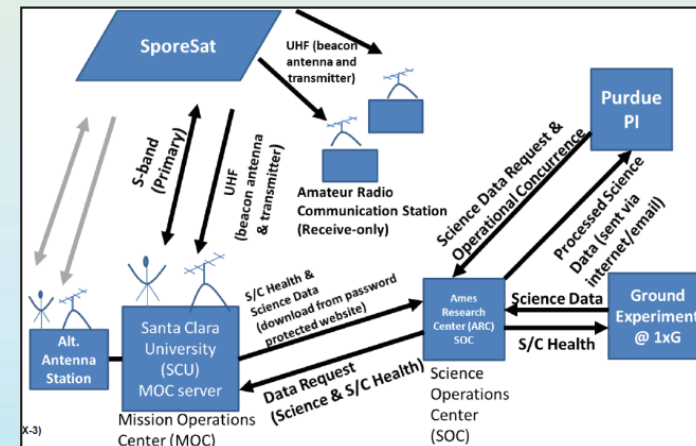
Architecture (Powerpoint)



Experiment FFBD and Timeline (Powerpoint)



Phase Description and Timeline (Powerpoint)

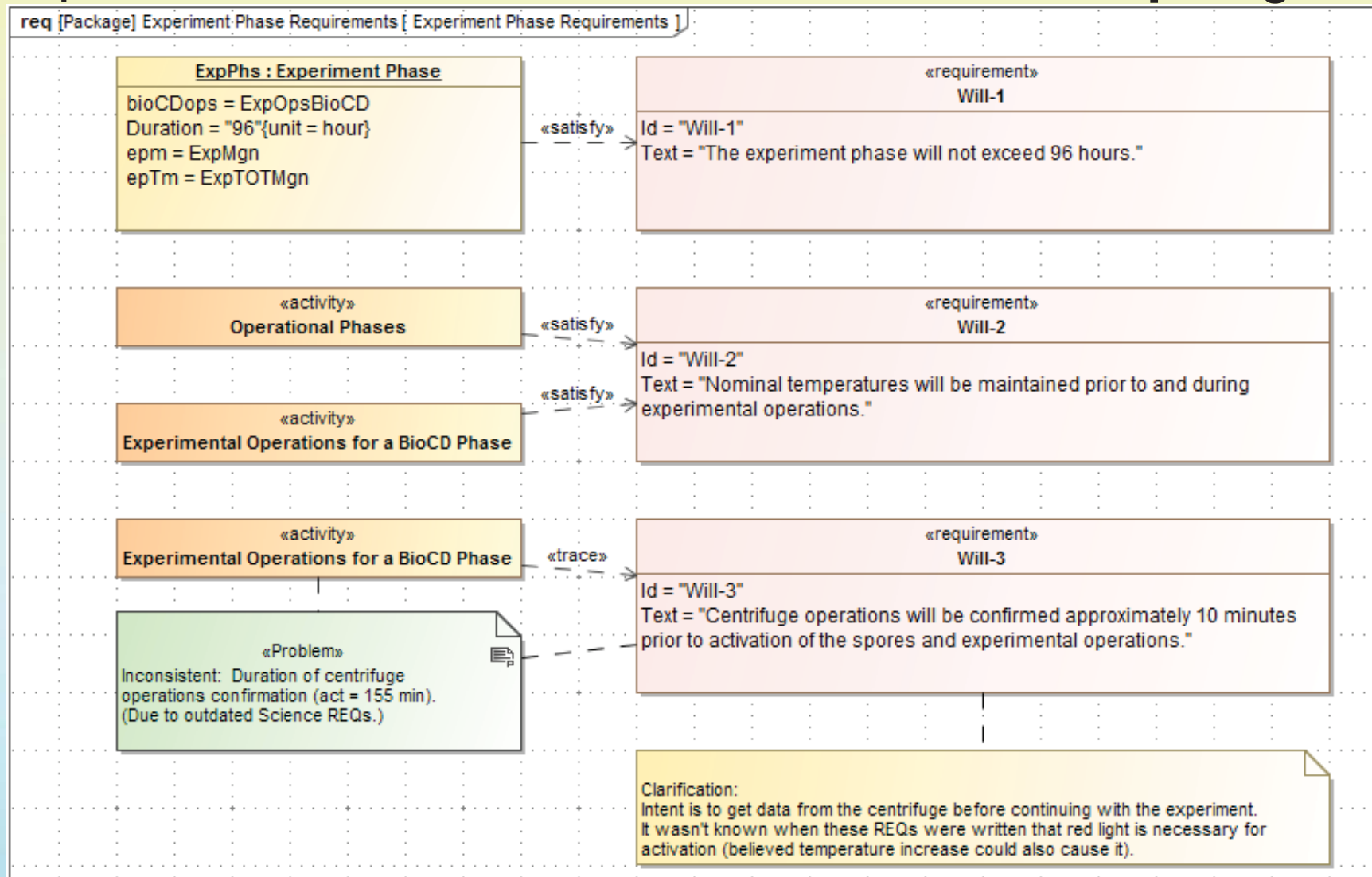


Communication Architecture (Powerpoint)

Document:
Requirements

Results

Model:
req Diagram



Document:
Requirements

Results

Model:
Satisfy Matrix

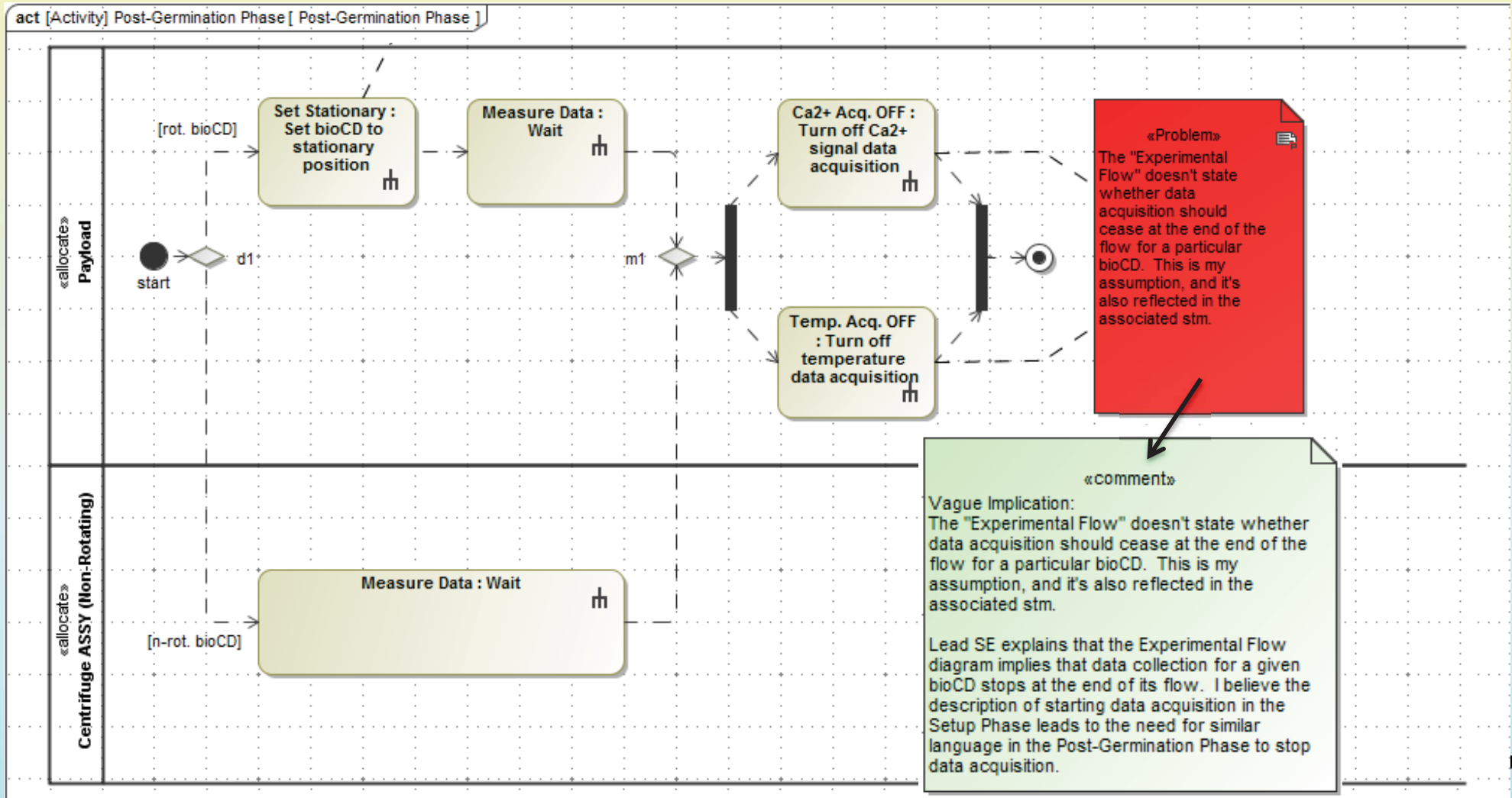
	S41 Baseline Exp...	S46 Ca2+ Differ...	S45 Control of Ar...	S45.2 Maximum ...	S45.1 Minimum P...	S49 Data Acquisi...	S54 Data Acquisi...	S43 Experiment ...	S53 Experimental...	S42 Spore Growt...	S42.2 Spore Gro...	S42.1 Spore Gro...	S42.3 Spore Gro...	S50 Time Spacing...	S52 Time Spacing...	S51 Time Spacing...	S44 Variable Gra...	S48 Voltage Data...	S47 Voltage Data...	Will-1 Will-1 [Scle...	Will-2 Will-2 [Scle...	Will-3 Will-3 [Scle...	Will-4 Will-4 [Scle...	Will-5 Will-5 [Scle...
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Behavior		1						1									1			2	1	1		
Structure	1	1		1	1	1	1	1	1		1	1	1	1	1	1	1	2	3	1				1
Launch Vehicle																								
Lower Level Detail		↗									↗	↗												
Magnet																								
Main Antenna																								
Main Battery																								
Main Transceiver																								
Master PCB																			↗					
Mission Team																								
Motor ASSY				↗	↗																			
Payload								↗																
Payload Interface PCB							↗		↗															
Payload PCB																								



Document: Phase Description

Results

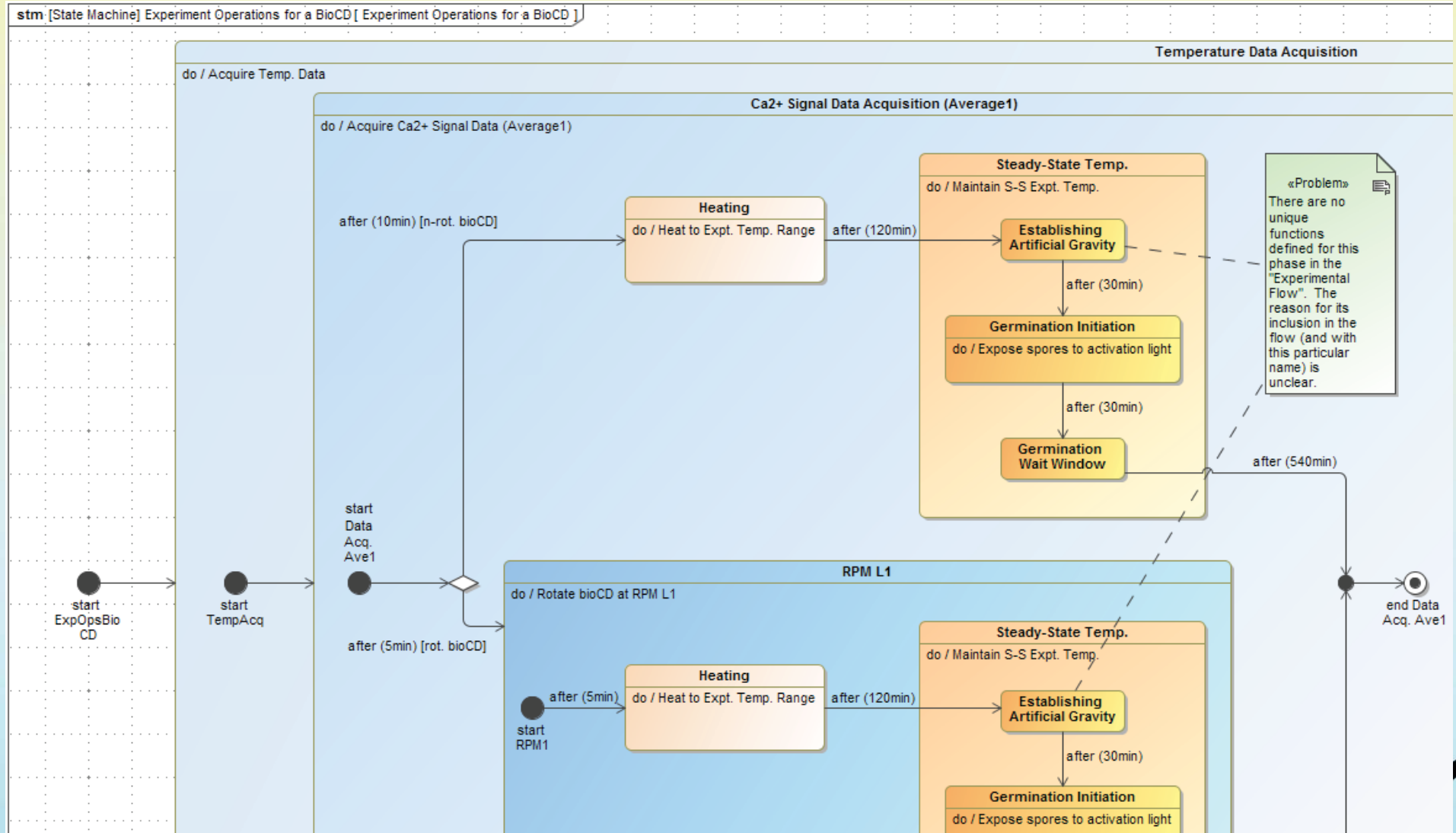
Model: act Diagram



Document: Experiment Timeline

Results

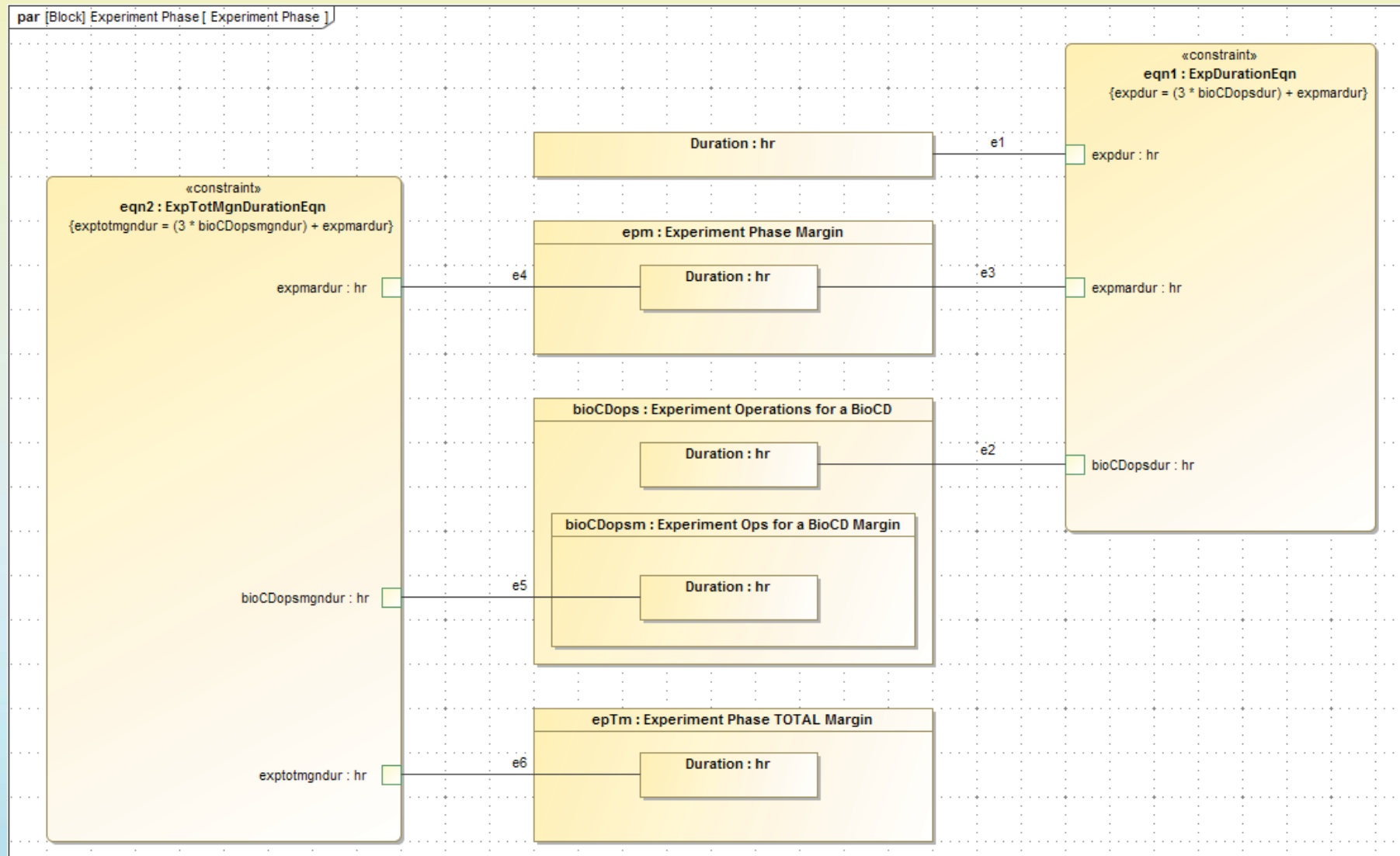
Model: stm Diagram



Document:
Experiment Timeline

Results

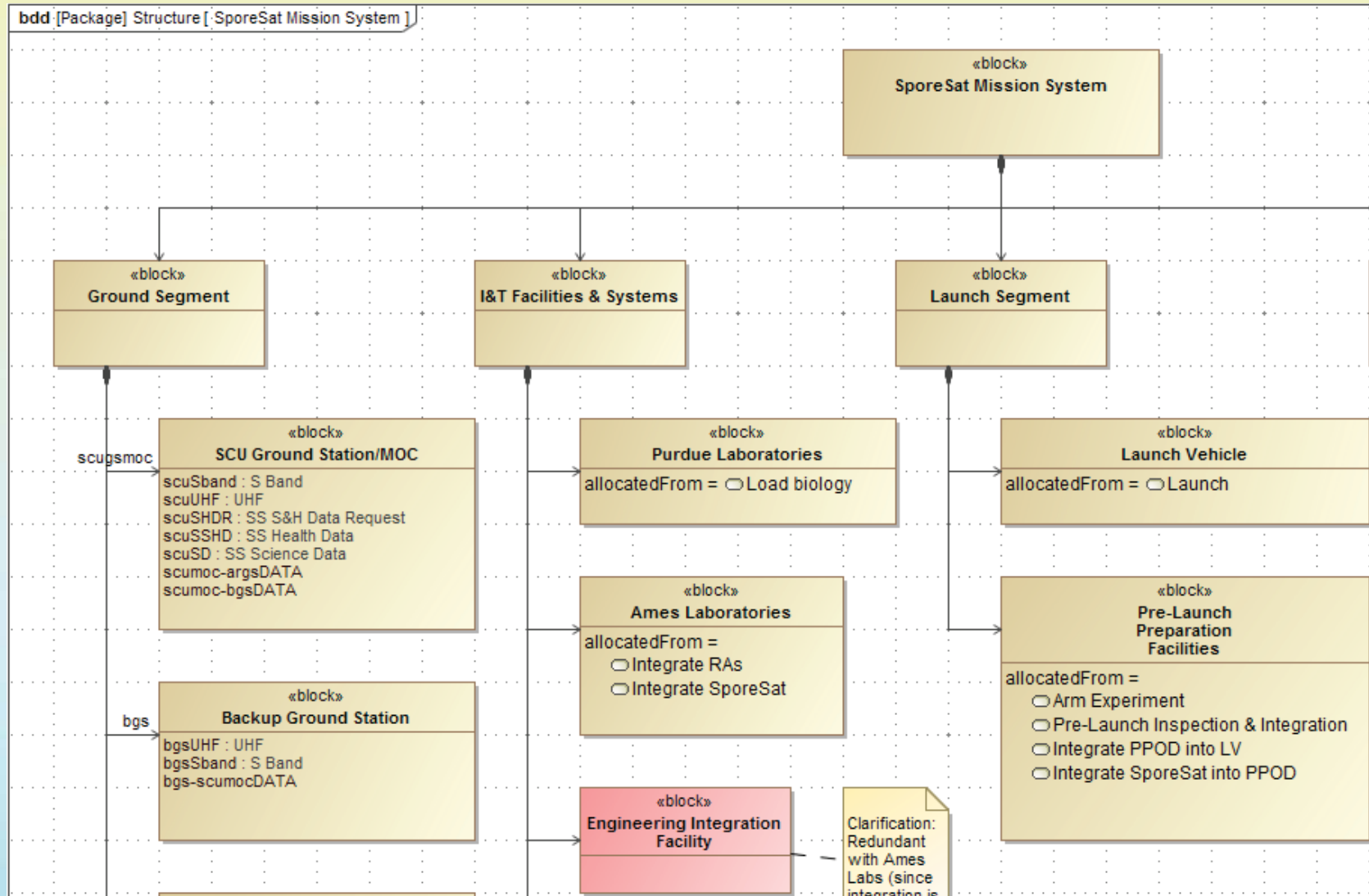
Model:
par Diagram



Document:
Architecture

Results

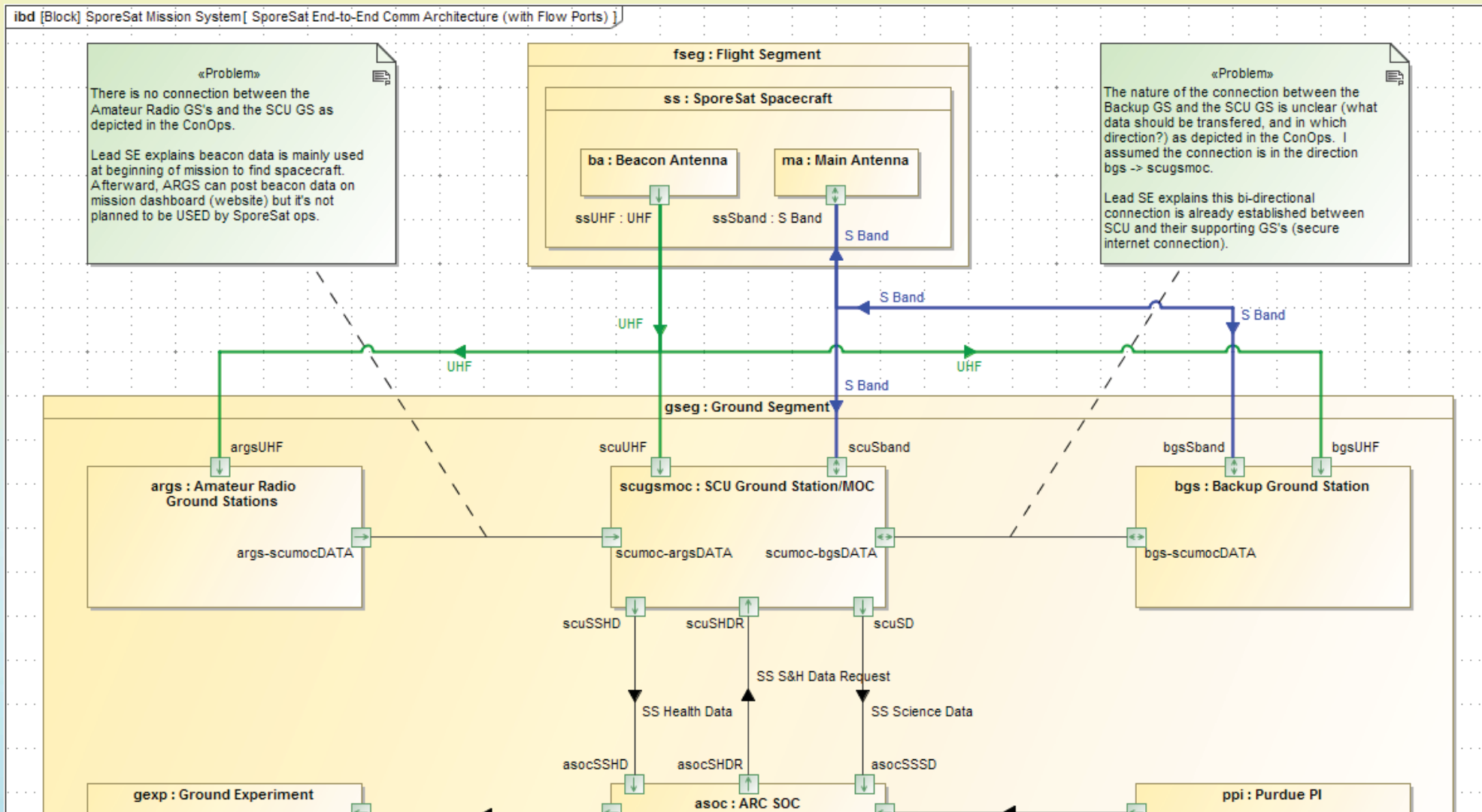
Model:
bdd Diagram



Document: Comm. Architecture

Results

Model: ibd Diagram



Results

Tracked Issues

		Resolved: S/C po...	Redundancy: Thi...	Nomenclature In...	Resolved: Unclea...	(1/29/13) This is ...	Resolved: The "E...	Vague Implicatio...	Nomenclature In...	Outdated Docum...	Outdated Docum...	Resolved: Not ex...	Resolved: The d...	Redundancy: Re...	Resolved: This is ...	Inconsistency: O...	Resolved: The re...	Nomenclature In...	Resolved: There ...	Resolved: The n...	Outdated Docum...	Outdated Docum...	Outdated Docum...	Resolved: The re...	Outdated Docum...	Outdated Docum...	Outdated Docum...	Outdated Docum...	Redundancy: Mo...	Outdated Docum...	Outdated Docum...	Outdated Docum...
<div><div></div><div>Behavior</div></div>																																
<div><div></div><div>Structure</div></div>																																
<div><div></div><div>Experiment Phase Requirements</div></div>																																
<div><div></div><div>General Requirements</div></div>																																
<div><div></div><div>Ground Experiment Requirements</div></div>																																
<div><div></div><div>Transport Phase Requirements</div></div>																																

Issues	
Total	41
Resolved	14
Unresolved (issues with Requirements / ConOps)	27

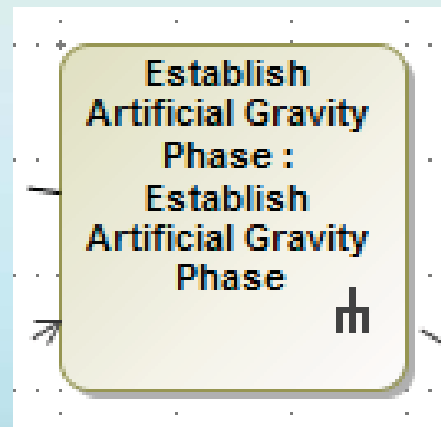
Unresolved	
Vague Implication	2
Not verifiable as written	3
Redundancy	4
Nomenclature Inconsistency	5
Outdated Documentation	13

Results

Issue: Ground Experiment Requirements \leftrightarrow ConOps

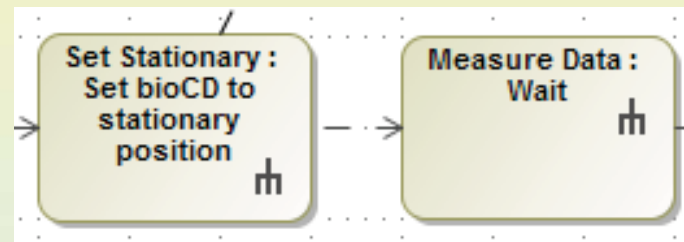
Satisfy Dependency Matrix	S55 Ground Expe...	S56 Replication o...	Will-10 Will-10 [S...	Will-11 Will-11 [S...	Will-12 Will-12 [S...	Will-13 Will-13 [S...	Will-14 Will-14 [S...	Will-7 Will-7 [Scie...	Will-8 Will-8 [Scie...	Will-9 Will-9 [Scie...
Structure	1	1					1			1

Issue: ConOps Missing Information

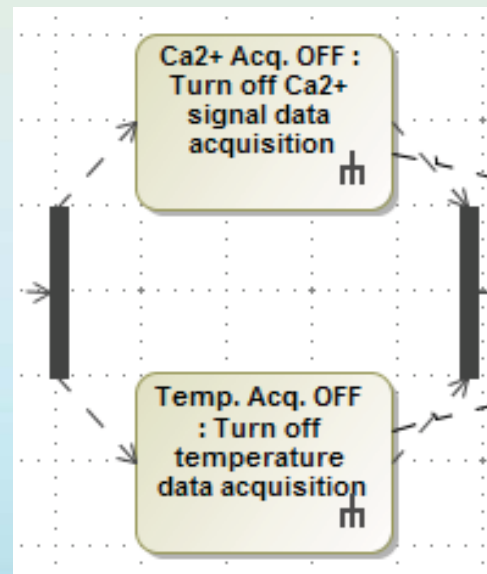


Results

Issue: ConOps \leftrightarrow Experiment Phase Requirements

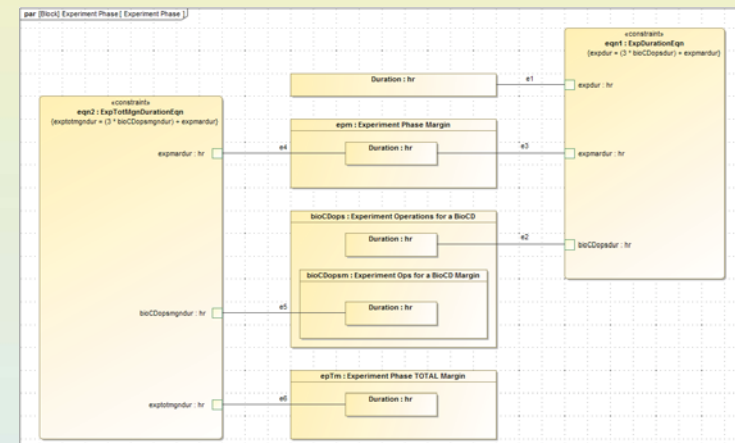
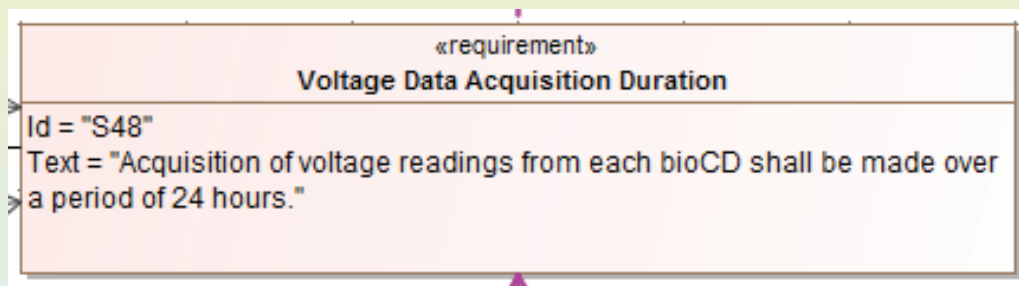


Issue: ConOps Missing Information



Results

Issue: ConOps \leftrightarrow Experiment Phase Requirements Inconsistencies



Experiment Phase Duration:

- Experimental Flow Diagram \rightarrow 72 hours
- Operational Phase Diagram \rightarrow 96 hours
- Experiment Phase Requirements $\rightarrow \leq 96$ hours



Results

- Issues with SysML / Modeling Tool
 - No smarts to the relationships between requirements and/or model elements
 - Time representation



Implications of Research

MBSE



YEA?



NAY?



Future Work

- Determine metrics to measure MBSE benefits quantitatively
- Study MBSE approach in various settings
 - Government vs. Industry vs. Academia
 - Large vs. small missions
 - ROI for short and long term
- Study MBSE benefits when used throughout full life-cycle

